

TROMS

Innovation Package for adaptation and resilience



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Arctic demo-site

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ABOUT THIS DOCUMENT

The Impetus project

The EU-funded IMPETUS project (2021-2025) helps accelerate Europe's climate adaptation strategy and meet the European Union's ambitions to become the world's first climate-neutral continent by 2050. The objective is to turn climate commitments into tangible, urgent actions to protect communities and the planet.

Central to the IMPETUS project are the Resilience Knowledge Boosters (RKB), an innovative approach to combine the voice and experience of local and regional communities with the power of digital tools. In this way, policy-makers, businesses, citizens and other stakeholders can explore climate change evidence together, share information, learn, test ideas and co-create knowledge, discover which actions could constitute the best paths towards climate adaptation, and so contribute to decision making and policies.

IMPETUS has demonstration sites in 7 European biogeographical regions. Here, multidisciplinary teams and local stakeholders work together to shape adaptation by testing diverse solutions for the local impacts of climate change and exploring alternative pathways for risk reduction and transformative change.

The innovation packages

Innovation packages are built on major IMPETUS results achieved at demo-site level. They are composed of three blocks:

1. RKBs and their digital dimension for engaging stakeholders and boost knowledge for developing a long-lasting territorial resilience.
2. Adaptation pathways, to explore alternative sequences of measures to address specific climate risks at the regional level.
3. Portfolio of climate adaptation solutions, to learn from alternative adaptation options, tested or discussed across the project, and evaluated through a common set of criteria.

The objectives are:

- To present an organised synthesis of results achieved at demo-site level within the IMPETUS project.
- To facilitate mutual learning among demo-sites by comparing different solutions to face various climate risks.
- To facilitate replication and upscaling.
- To highlight major limiting or success factors that hinder or enable the progress toward adaptation and resilience.

Reader's guide

This document provides an overview of the climate risks in the region and a synthesis of the knowledge, tools and solutions produced, tested or analysed in the framework of the IMPETUS project. After the section presenting the climate risks, the document is organized following the three building blocks of the Innovation package: RKBs, Adaptation Pathways, and Portfolio of Solutions. Each block includes a synthesis of main results achieved during the project, followed by a 3-angle evaluation proposed by demo-site leaders after extensive consultation with stakeholders:

- Exploitation potential for further boosting knowledge and adaptation in the region.
- Major gaps and needs to translate ideas into concrete commitments.
- Potential for fostering transformational adaptation.

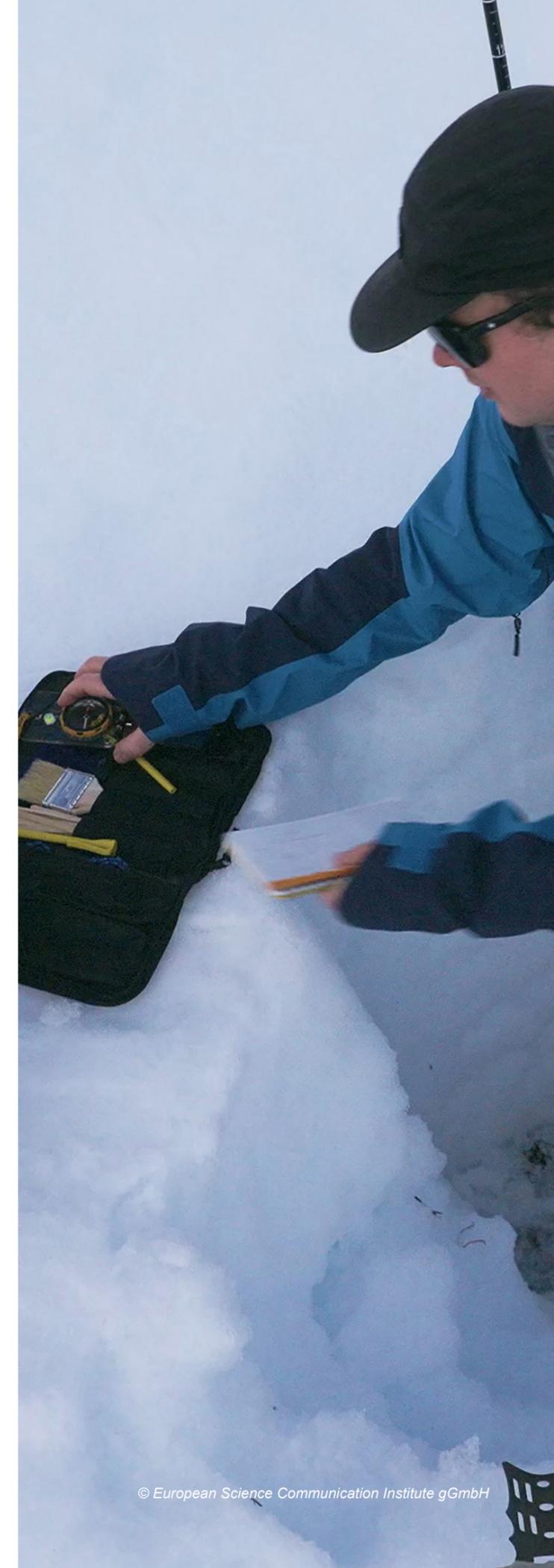
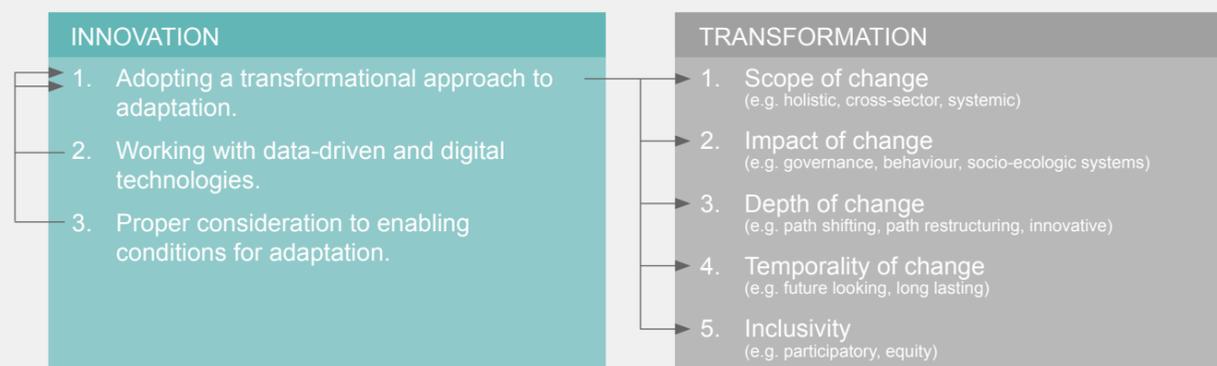
Expert judgment was used to score the evaluation elements using a 1 to 5 scale.

Key concepts: Innovation and Transformation

The "innovation component" of innovation packages is related to:

- The incorporation of transformational approach: adaptation that changes the fundamental attributes of a social-ecological system in anticipation of climate change and its impacts (IPCC, 2022; Cools et al., 2025).

- The inclusion of new technologies and tools.
- The inclusion of non-structural solutions (governance, finance and knowledge) as enabling factors to implement adaptation interventions.



THE CLIMATE RISKS OF THE REGION

Located beyond the Arctic Circle, Troms is Norway's second regions. It faces diverse climate risks including landslides, avalanches, glacial retreat, and sea-level rise. With a dispersed population and strong dependence on fisheries, tourism, and traditional livelihoods like reindeer herding, local communities and infrastructure are increasingly exposed to climate hazards.

Rising sea temperature

Due to climate change, ocean waters are getting warmer and more acidic. This can lead to disease spreading, harmful algal blooms, species displacement and the introduction of alien species, with the disruption of local ecosystems and impacts on the entire food chain. This has a cascading impact on maritime activities, like fisheries and aquaculture, whose development relies on healthy ocean conditions. Critical issues, scalable and transferable solutions can be implemented, focusing on water recycling and reuse, resource efficiency and conservation, decision-making tools, stakeholder engagement, public awareness and policy improvements.

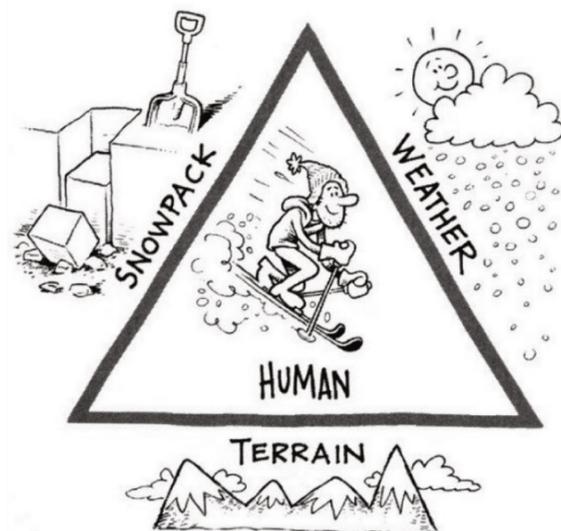
Floods

Sea level rise and the rising frequency of marine storms and related storm surge levels put coastal communities, businesses and infrastructure at risk of floods. Most of villages and cities are built in low-lying areas along the coast and, in recent years, some have undertaken large developments close to the shoreline. This makes the coastal area of Troms particularly vulnerable to floods. An increased risk

of pluvial floods is also expected due to a projected increase in precipitation due to climate change.

Avalanches

Avalanches exert a threat to human life and infrastructure in Troms county. Avalanches are especially dangerous for skiers during the cold season, can cause road closure, isolation of communities and in the worst cases fatalities. Climate change (including changes in winds, increasing temperature and rain precipitation) have complex effects on the avalanche formation, with a possible increase in the severity of avalanche events, but also a likely change in the main characteristics of avalanches, with fewer dry and more wet avalanche events (slushflows).



Drivers that form the avalanche risk for humans: terrain, snowpack and weather. © Avalanche.org.



A PLATFORM TO EXCHANGE AND BOOST KNOWLEDGE

Content

The RKB (Resilience Knowledge Booster) web platform presents and explains the regional challenges posed by climate change and helps exploring possible solutions. The Solutions part of the platform includes three sections to explore: the Marine Spatial Planning Framework, the Digital twin for Tromsø city and the Avalanche and Slush flow assessment.

The *Adaptation Pathways* section includes a conceptual model for the avalanche risk (Impact chain) showcasing how hazard, exposure, and vulnerability elements interact to generate the risk

for the increasing risk in human injury, loss of life, and loss of property due to avalanches and climate change.

The platform is available at <https://impetus.mantisims.gr/knowledge-boosters/arctic/>.

Marine Spatial Planning

A map-based web client presents the climate change risks for the coastal area. Users can visualise and evaluate how storm surges, avalanches and floods may affect the coastal zone and interfere with the

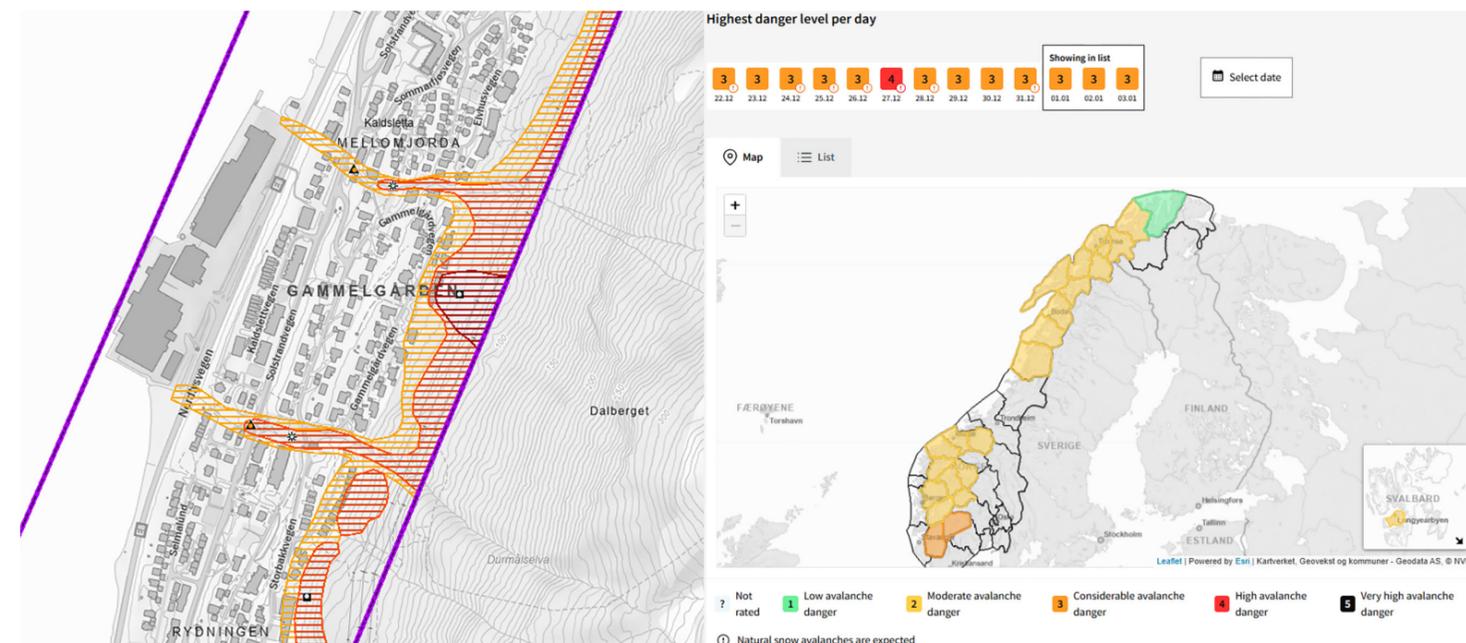
existing uses, plans and regulations. Interactive functionalities allow users to upload new datasets and share ideas and suggestions about possible adaptation measures.

Digital twin for the Troms city

A 3D visualisation tool of the city allows users to understand to what extent floods caused by marine storms and extreme precipitation can affect the coastal urban area in different scenarios. The tool also provides a platform of discussion about possible adaptation measures to mitigate this risk.

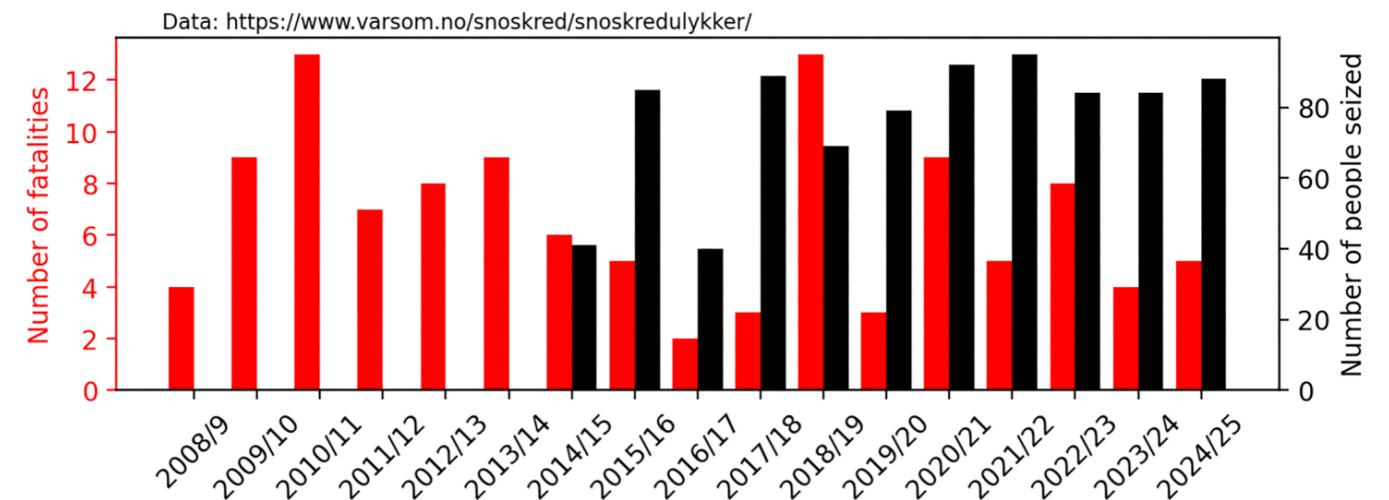
Avalanche and Slush flow assessment

Hazard zones for slushflows can be viewed in the Troms digital twin. Users can also access the scientific publication about using statistical models to predict avalanche danger in Northern Norway.



Hazard map with hazard zones within Tromsø city limits. There are three hazard zones: orange, red and deep red representing the probability of a 1/5000-, 1/1000- and 1/100-year event respectively. (Map Catalogue at NVE)

Example of an avalanche danger forecast in Norway for 01.01.2024 (Varsom Snøskredsvarsler)



Avalanche fatalities in Norway since 2008. (<https://www.varsom.no/snoskred/snoskredulykker/> "Varsom Snøskredsulykker").

RKB - Exploitation potential

STAKEHOLDERS INTEREST

score
4/5

MAIN STAKEHOLDERS INVOLVED

Academia, Industry and economy, public authorities and the general public

The RKB was developed with the involvement of Academia (UiT - The Arctic University of Norway), Industry and economy (SWECO & GeoData for the development of the digital tools), national and local authorities (Troms Fylkeskommune TFK; Norwegian Water Resources and Energy Directorate NVE), and the general public through public events, newspapers

FEEDBACK FROM STAKEHOLDERS

Most stakeholders from the municipality considered the RKB an important tool for climate adaptation at the local and regional level. Specifically, the digital twin and the marine spatial planning tool are useful as they can display projected climate risks in future scenarios. This could easily be integrated with local authorities' maps and regulations. By providing data, other institutions directly contributed to some RKB solutions (Digital Twin, Marine Spatial Planning Tool).

The national institution which produces slushflow warnings (NVE; Norsk vassdrag og eneridirektorat) demonstrated specific interest in the slushflow classification system that might be integrated in the current early-warning system.

The Troms municipality is interested in the citizen-jury approach, but since the establishment requires financing, there is currently no attempts to implement it.

STRENGTHS

score
3/3

A POWERFUL TOOL TO VISUALIZE RISKS AND SOLUTIONS

RKB DIGITAL DIMENSION COMPONENT	SCORE
Visualisation (layout, images, graphic design)	4
Knowledge content (quality and type of information displayed)	3
Interactive functionalities (animations, customised navigation, dashboards)	3
Feedback collection tools (pools, chats)	3

OPPORTUNITIES FOR RKB USE

score
3/5

Three tangible opportunities for using the RKB in the region were identified:

- Support the Regional Plan for climate adaptation. The plan preparation is ongoing and will be finalized and ratified next year by the regional government.
- Support the regional spatial planning, both on land and at sea. The DT/MSP received interest from parties like the Norwegian Mapping Authority and the Institute of Marine Research who are part of the governance and spatial planning system and who provided data for the tool implementation. The MSP tool is in the process of being implemented into several departments of the Fylkeskommune (local governance).
- Support the early warning system of the region. The slushflow classification has generated the interest of NVE, the national authority for delivering slushflow early warnings. This will lead to follow-up work to integrate the slushflow classification into their early-warning system.

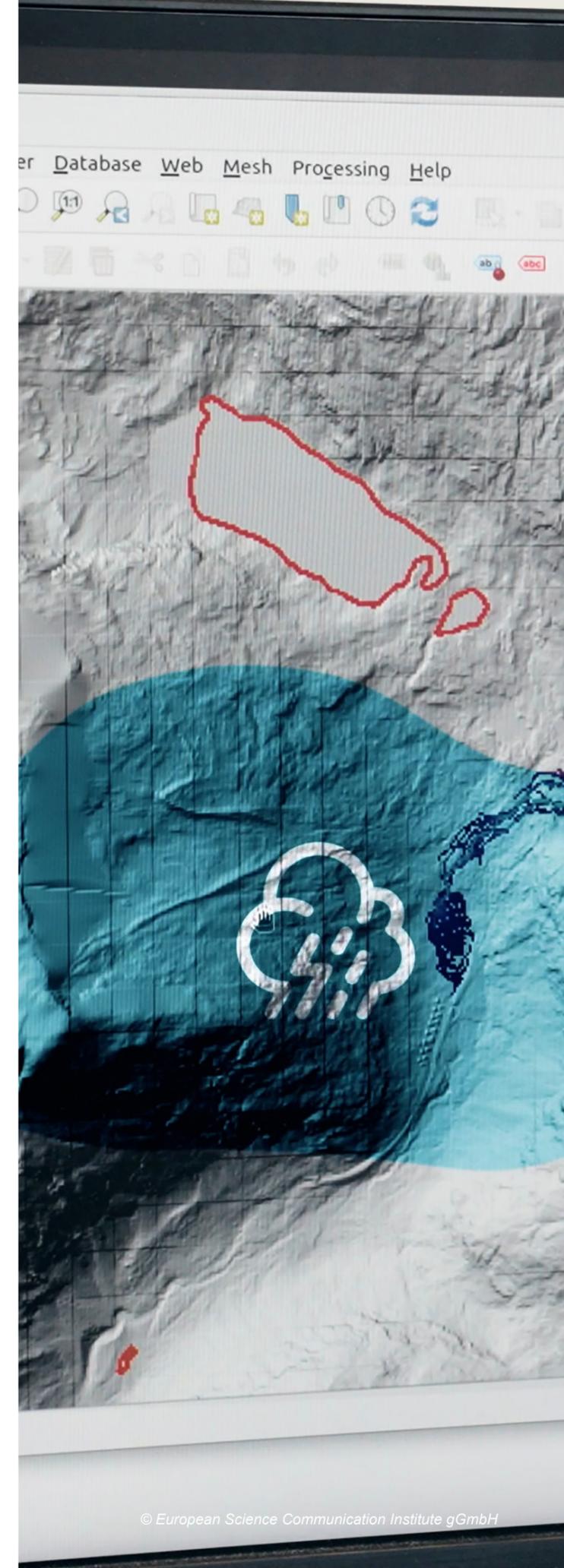
RKB - Gaps & needs

CHALLENGES FOR PLANNING AND DECISION MAKING PROCESS: more capacity to use information and dedicated financing

PRIORITY	CHALLENGE
1	Capacity challenges (ability and motivation to use knowledge for action)
	Finance challenges
2	Governance challenges
3	Knowledge (availability of information)

WHAT TO IMPROVE

Integration between RKB tools and those already used for spatial planning in the region is only partially achieved. In Norway, well-developed mapping tools and websites are available and currently support decision-making. If RKB could be linked to existing functionalities, this would generate longer-term thinking and planning, mainstreaming climate change into existing policies. Dedicated time, effort and funding is needed to achieve this integration.



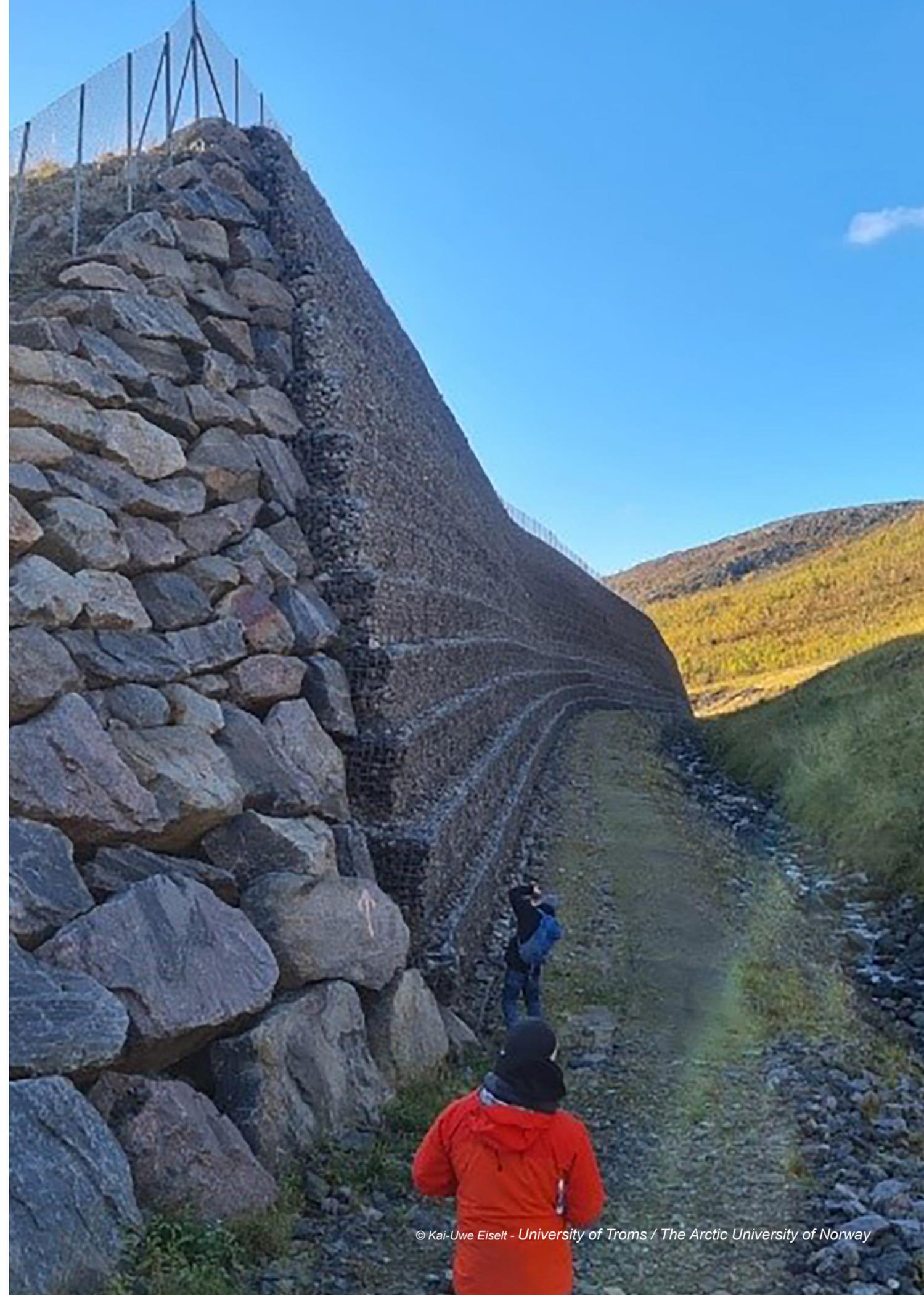
RKB - Transformational potential

A MULTI-SECTOR, SCALABLE, FLEXIBLE AND NOVEL APPROACH FOR LONG-TERM PLANNING

The RKB platform supports informed decisions for different sectors, addressing the marine space, the coastal area and the urban environment, considering multiple risks posed by climate change. New layers of data about marine - or geo- hazards can be added to the MSP and DT tools, while rapidly evolving phenomena, are incorporated in the slushflow tool, making the overall system quite dynamic in capturing new available knowledge.

At the other hand, a more inclusive approach would be necessary to really boost transformational adaption, by addressing specific needs of the most vulnerable communities. For example, road closures, which can be implemented to prevent floods and slushflows, can result in the geographical isolation of remote areas, requiring careful evaluation and support to people.

TRANSFORMATION ELEMENT	SCORE
SCOPE: The RKB platform includes a multi-sector approach	4
SCOPE: Developed at scale or easily scalable	4
SCOPE: Responsive (flexible) to changing conditions	4
DEPTH OF CHANGE: Novel approach for the region	4
TEMPORALITY: Long-term vision/expected to produce long-term and durable outcomes	4
INCLUSIVITY: Co-developed/discussed with stakeholders	3
DEPTH OF CHANGE: Expected to generate radical shift or large restructuring in your region	2
INCLUSIVITY: Consideration for the equity of measures, attention for vulnerable groups	1



ADAPTATION PATHWAYS TO ADDRESS THE AVALANCHE RISK

Content

INTRODUCTION

Adaptation pathways are sequences of adaptation measures that are planned to be progressively implemented to cope with the increasing or evolving risks posed by climate change. The implementation of additional, different or larger measures is triggered when current adaptation measures and policies are no longer effective to withstand climate change (tipping points), marking the need to shift to different and more effective solutions. The IMPETUS methodology for developing adaptation pathways (AP methodology, IMPETUS, 2024) was applied in the seven project demo-sites.

Stakeholder interactions were performed in each region with formal events and informal exchanges. Interactions were continuously ensured from the beginning and across all the process of pathway development, also considering that key stakeholders include public administrations and utilities. Stakeholders were specifically consulted for discussing adaptation options and adaptation pathways, and their feedback was used to refine or even change the final outcomes.

The main objective of the proposed Adaptation Pathways (IMPETUS, 2025) is to reduce the risk of injury and loss of life associated with avalanches in the Troms county, and to protect property against avalanche and slush-flow hazards. Forecasts of avalanche danger have been provided by the Norwegian Water Resources and Energy Directorate (NVE) on a regional scale since 2013. The pathways suggest the implementation and further development of modelling tools and other methodologies in existing forecasting systems, in order to improve the quality of avalanche-risk predictions. The

pathways also suggest improvements of early-warning systems for the protection of, for instance, roads and infrastructure. Moreover, the pathways consider the need for strengthened information strategies, improved education of mountain users, and enhanced organisation of rescue operations. Finally, regulation changes, updated hazard zoning, and structural measures are proposed.

THE IMPACT CHAIN

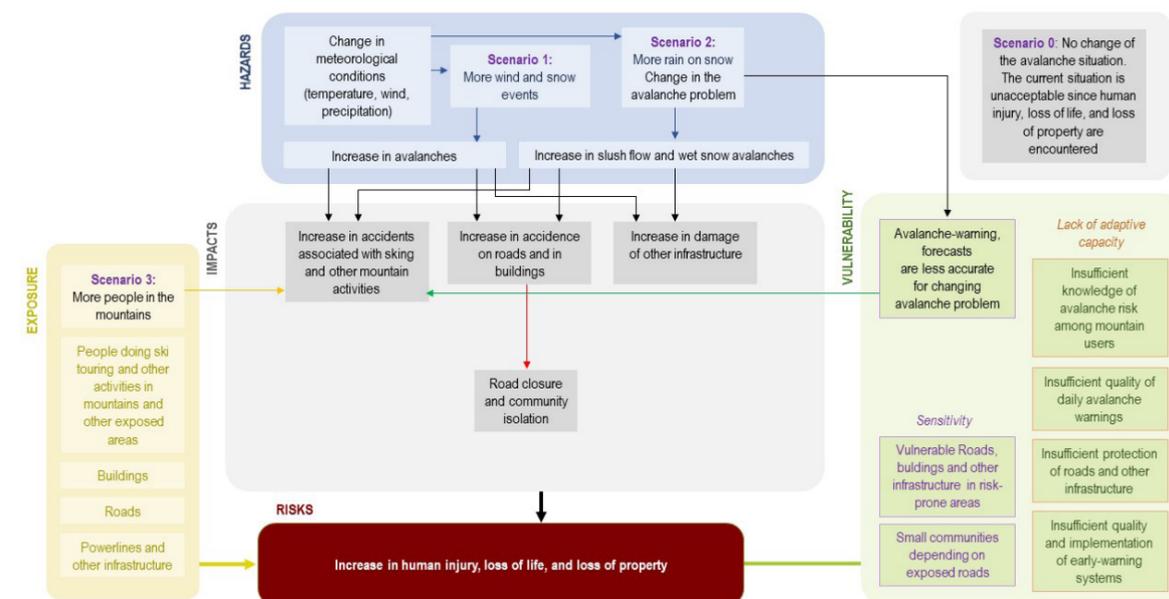
Impact chains (GIZ and EURAC, 2017; Zebisch et al., 2022, 2023) are useful tools to delineate conceptual models for climate change risk assessment. They are cause-effect chains that include all major factors and processes leading to specific climate risks in a specific context.

The impact chain for the Troms County show how avalanches are strongly impacted by local weather- and climate conditions. The most important variables for avalanche conditions are a combination of precipitation (both snow and rain) and wind. A possible increase in the number and severity of wind and snow events can worsen the avalanche risk for people, services and infrastructure. Avalanches may also appear in areas characterised by steep slopes where avalanches have not been observed before.

In addition, higher temperatures associated with climate change may lead to more precipitation in the form of rain during the winter season. Hereby the

avalanche problem may change from being mostly associated with dry-snow avalanches to become more characterised by wet-snow avalanches and slushflows. A consequence of such changes could be a less accurate forecast of the avalanche danger because of unprecedented conditions. This may lead to an increase in accidents associated with skiing and mountain tourism in general.

Finally, Troms is experiencing an increasing trend in winter tourism, meaning an increase in people in risk areas, which is expected to lead to more accidents. The communication of danger and risk becomes extremely important. Snow conditions in northern Norway are often different from those that tourists are familiar with, potentially leading to wrong and risky decisions.



THE PATHWAYS MAPS

Three alternative adaptation pathways (AP) are proposed to address the growing risk of avalanches and slushflows in Troms county, reflecting different approaches to risk management:

- **Alternative 1: Conservative or non-interventionist**

The *conservative or non-interventionist* pathway prioritises adaptation options that are inexpensive and interfere little with people's lives. This is likely the most socially acceptable pathway, especially if changes in avalanche-related accidents and fatalities do not increase. Conversely, if there is a considerable increase in avalanche-related accidents, this pathway may become less socially acceptable over time, due to public demand for more preventive measures.

- **Alternative 2: Progressive or mixed**

The *progressive or mixed* pathway includes most of the options proposed in the conservative pathway (partly prioritised differently) plus some more transformative measures. The exact timing of individual options in this pathway depends or may depend on the scenario, leaving large flexibility in options' sequencing.

- **Alternative 3: Transformational or interventionist**

The *transformational or interventionist* pathway seeks to implement most options as early as possible, hereby having a preventive character. More attention is given to the most transformational options and to structural measures, despite their high costs and potential impacts on the landscape. If a simultaneous increase in avalanche danger and tourism are encountered, this pathway appears the most acceptable since it is likely the most effective in reducing avalanche-related accidents and fatalities.

The adaptation options included in the pathways were grouped into three categories framed with different colours in the maps: (i) improvement of avalanche warning, (ii) improvement of danger/risk communication and (iii) hazard mapping and regulations. The options of the first category are deemed inexpensive, easy to implement, and generally feasible. The adaptation options of the second category are generally more expensive and their effectiveness partly depends on how much they are used. The third category includes the most transformational adaptation options.

Vertical arrows between adaptation options show that some of them partly or fully depend on the prior implementation of other options. The need for more data collection and research for options to be implemented is also highlighted and represented by an asterisk. A more detailed analysis of the measures included in the adaptation pathways is reported in the section "Portfolio of Solutions".

Four future scenarios were considered:

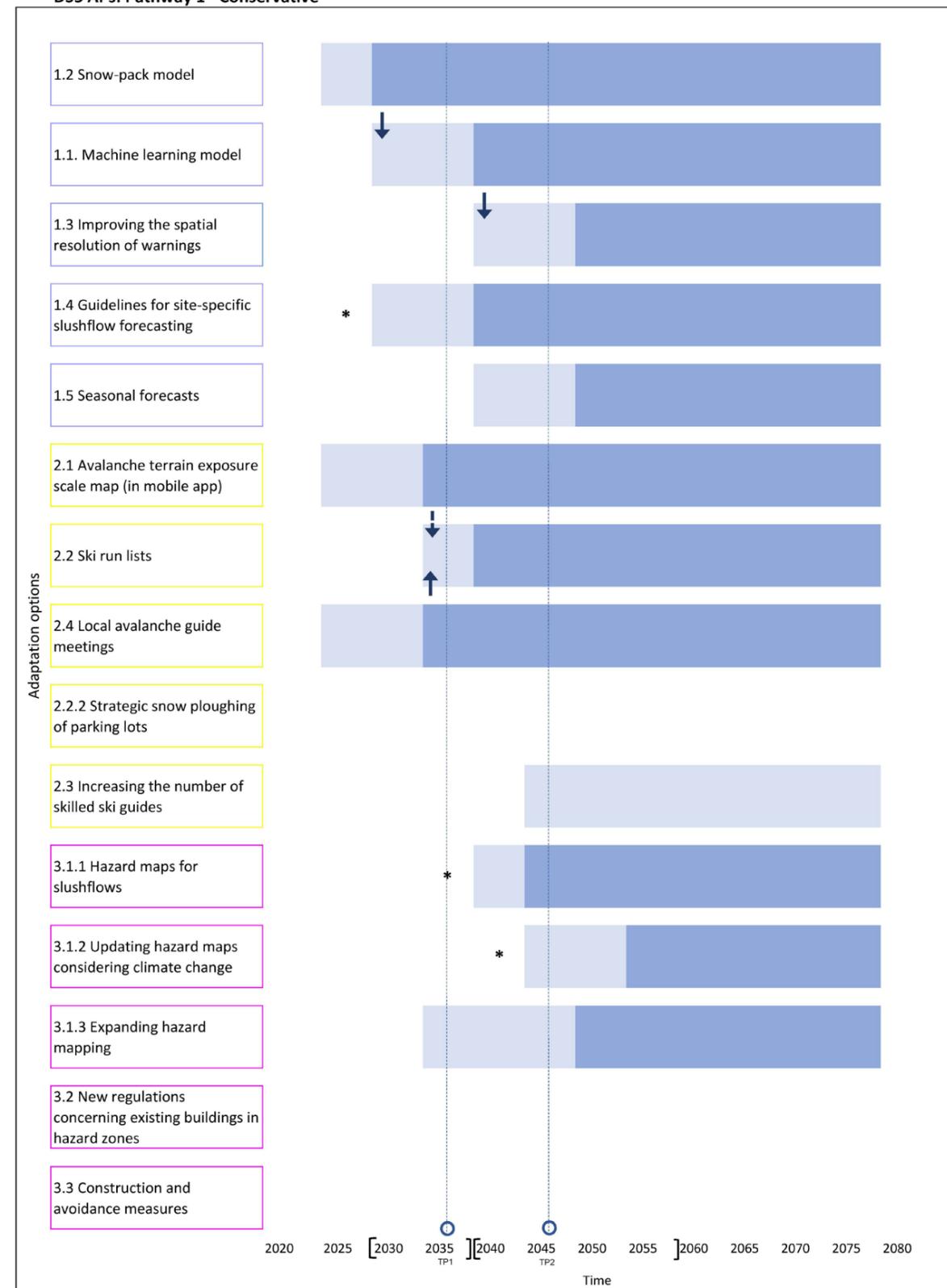
- **Scenario 0:** Baseline - avalanche activity is unchanged (or decreases).
- **Scenario 1:** Avalanche activity increases (increase in frequency and strength).
- **Scenario 2:** Avalanche problem changes (Shift in types of avalanches).
- **Scenario 3:** Shift in human activity with a general increase in tourism that may alter the amount of winter tourism in the region.

Given the above-mentioned scenarios, two possible tipping points are identified:

- Increase of avalanche-related accidents over one standard deviation of the last 20 years.
- Number of incorrect avalanche forecasts higher than the number of correct forecasts.

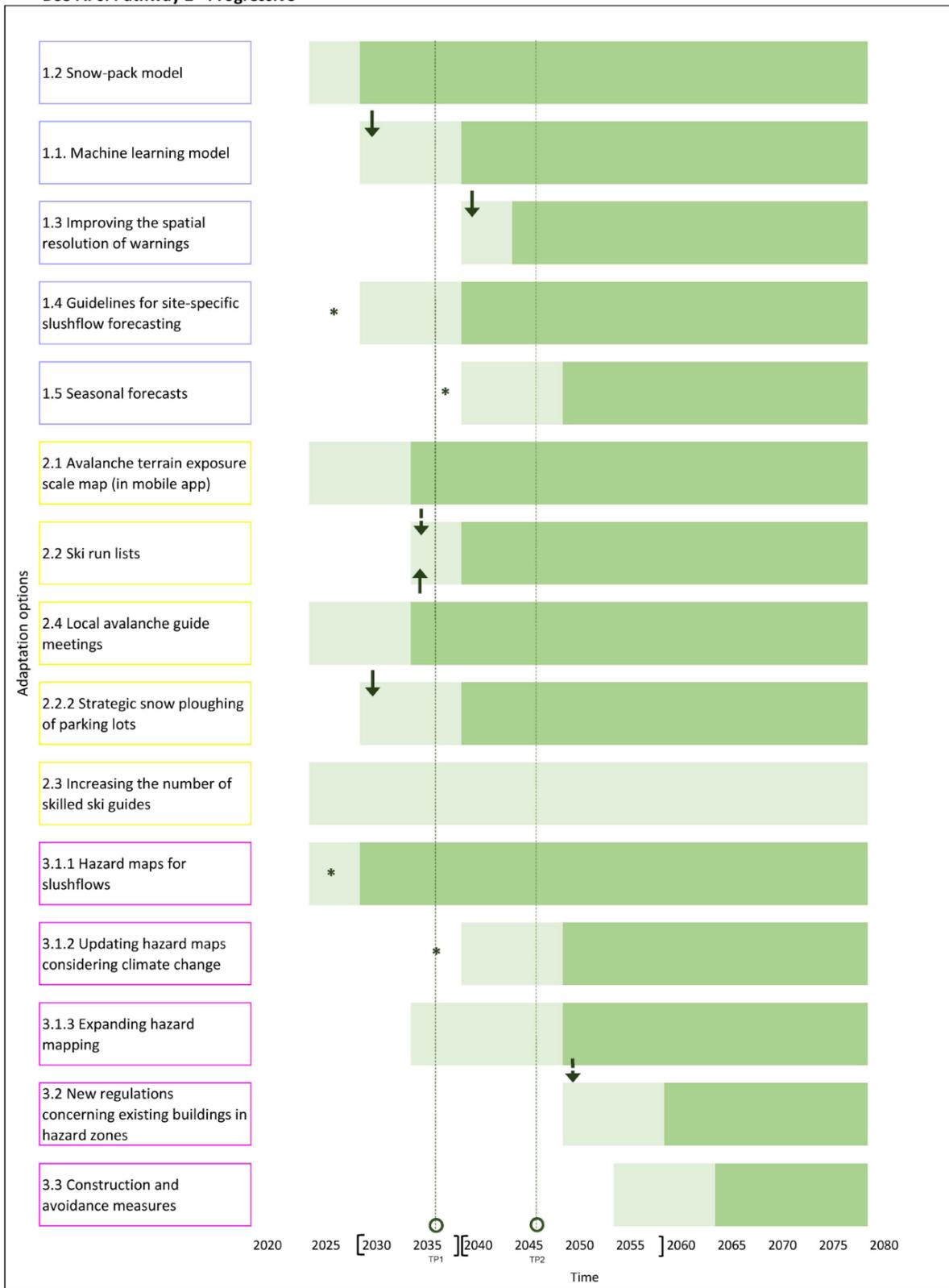
In the following graphs, the light colour of the bars represents the implementation time of measures, while the dark colour represents how long they stay in place. The two small circles represent the tipping points whose expected timing is highly uncertain and scenario-dependent.

DS5 APs: Pathway 1 - Conservative



Figures: DS5 Adaptation Pathways Maps

DS5 APs: Pathway 2 - Progressive



Figures: DS5 Adaptation Pathways Maps

DS5 APs: Pathway 3 - Transformative

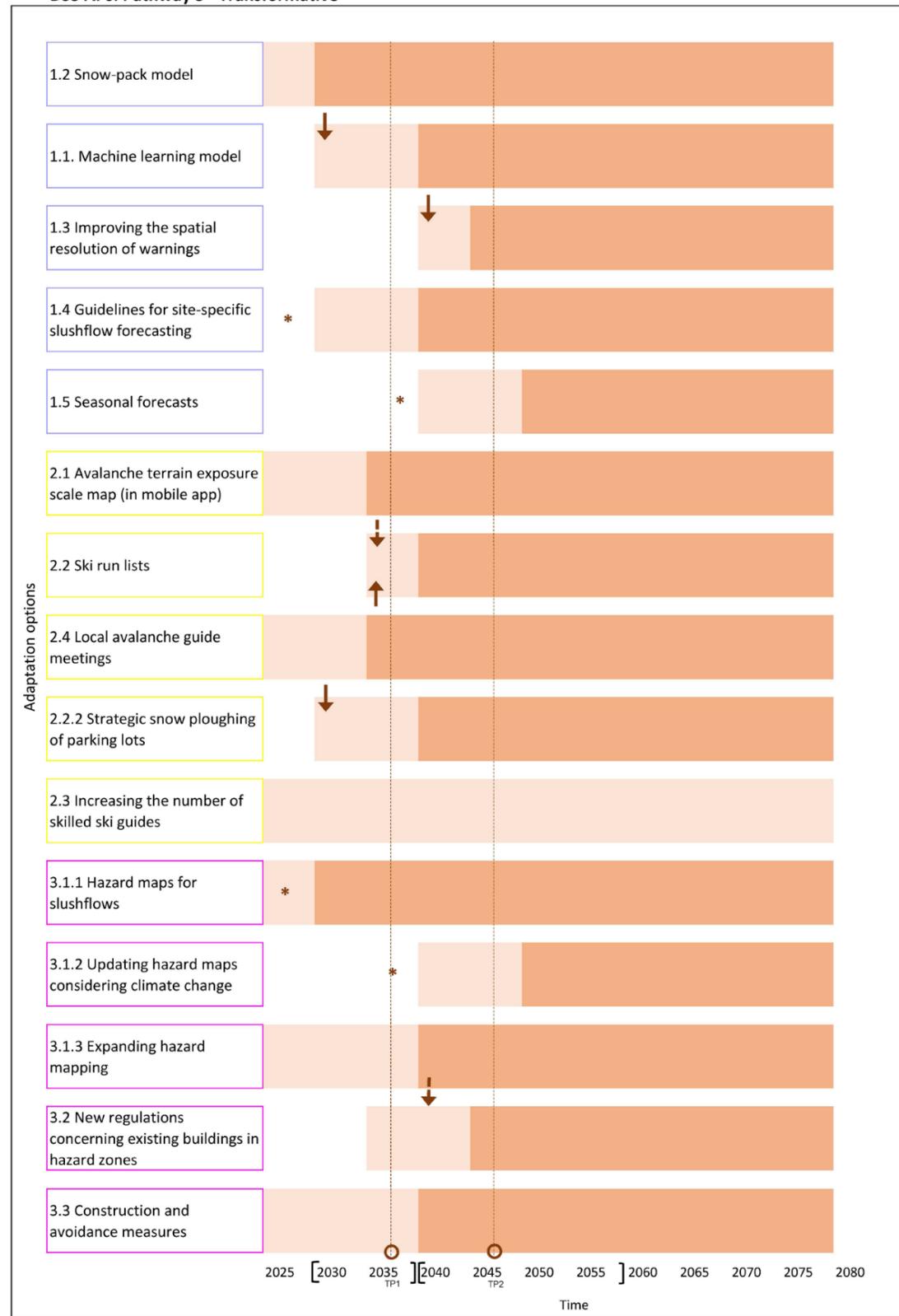


Figure: DS5 Adaptation Pathways Maps

Adaptation pathways - Exploitation potential

STAKEHOLDERS INTEREST

score
4/5

MAIN STAKEHOLDERS INVOLVED

Academia and local authorities

The main stakeholders involved in the creation of the adaptation pathways are the Center for Avalanche Research and Education (CARE) at the University of Tromsø (UiT) and Tromsø municipality.

FEEDBACK FROM STAKEHOLDERS

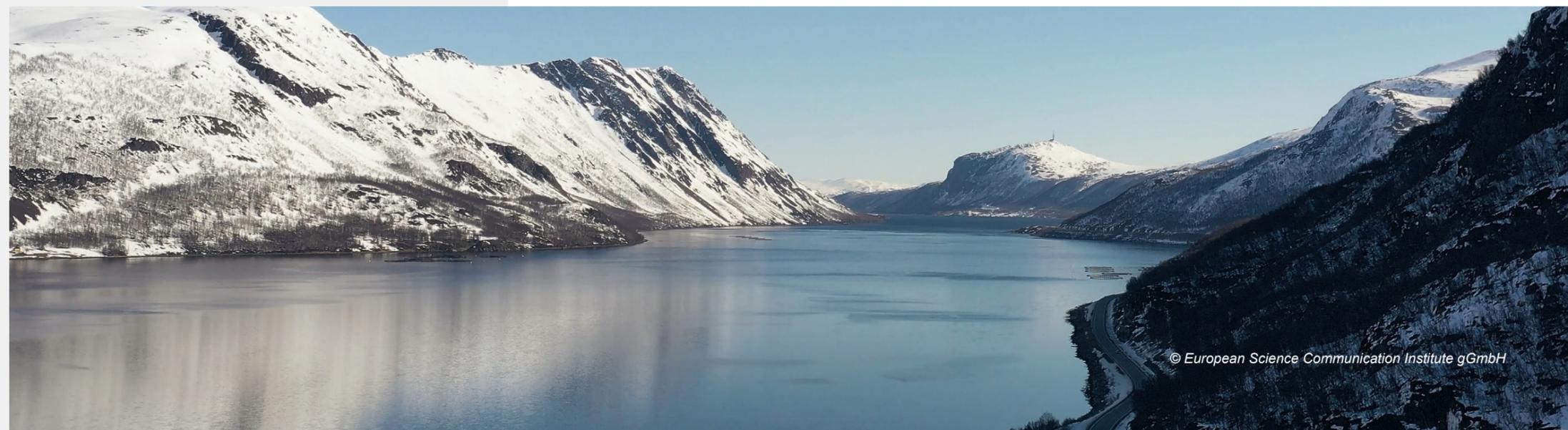
Stakeholders mainly contributed to the identification of adaptation options included in the pathways. In particular, CARE contributed to the definition of the options of category 2 (improvement of danger/risk communication), while the municipality specifically worked to define the options of category 3 (hazard mapping and regulations). A brief exchange with the Norwegian Energy and Water Resources Directorate (NVE) supported the identification of the adaptation options of category 1 (improvement of avalanche warning).

Adaptation pathways were finally presented to stakeholders. The feedback was generally positive, since stakeholders considered adaptation pathways a useful approach to manage the risk in a future looking perspective. The stakeholders were rather enthusiastic about communication and especially CARE expressed interest in future cooperation. However, keeping stakeholders engaged during the process of adaptation pathway development was challenging because this meant additional work for them. Moreover, it retrying to think about how our work fits into their already existing plans.

OPPORTUNITIES TO USE ADAPTATION PATHWAYS IN PLANNING/DECISION

score
3/5

No direct opportunities were identified. However, the stakeholders considered the approach helpful. Rather than a direct opportunity for Adaptation Pathways use, the work might be considered a stepping stone for future work and a guide for possible avenues to pursue. The project deliverable with the results of the work and a planned scientific paper might help increase the work visibility and therefore increase the stakeholder awareness of adaptation options in future planning, potentially complementing existing regional plans.



Adaptation pathways - Gaps & needs

CHALLENGES - HOW TO TRANSLATE INTO PRACTICE: Governance first!

The largest challenge in translating the Adaptation Pathways into practice is related to:

- **The novelty of the approach:** stakeholders were not familiar with the adaptation pathway methodology.
- **The institutional framework:** there is no established mechanism to formally integrate Adaptation Pathways into official adaptation plans.
- **The fragmented responsibility:** the adaptation pathways involve several distinct stakeholders (CARE, Tromsø municipality, NVE), making the full implementation of one specific pathway difficult to coordinate. A national and regional strategy to coordinate the pathway implementation would be needed, as well as a more centralised decision making. The success of such a strategy will likely depend on political willingness and on the acceptability of interventions in people's lives.

WHAT TO IMPROVE

More climate modelling would have been helpful to more robustly evaluate the range of future climate scenarios and the complex connection with the avalanche danger. This would also support a better definition of tipping points for adaptation. A possible alternative solution could be to use simple scenarios informed by existing knowledge of likely climate change (e.g., increasing the regional temperatures by 2°C and then predicting avalanche danger using machine-learning), which is a much cheaper approach than running complex numerical models.

PRIORITY	CHALLENGES
1	Governance challenges
2	Financial challenges
3	Capacity challenges (ability and motivation to use knowledge for action)
4	Knowledge (availability of information)

Adaptation pathways - Transformational potential

ELEMENTS OF TRANSFORMATION

A long-term vision for avalanche risk management

All the adaptation options are intended for indefinite application (some may last until technical progress calls for updates). If implemented, they would result in a **long-term** improved avalanche warnings, increased awareness of avalanche danger, safer skiing routes, more informed building regulations reduced avalanche-related accidents, fatalities, and losses and damages.

The approach and some measures included in the pathways are **new** to the region (e.g., machine-learning model for avalanche warnings), while others such as regulatory changes are not new in principle, but their extent may be new (e.g., for construction and avoidance measures). Approaches such as apps for ski-touring are relatively new, meaning that their acceptance and wide-spread use may take time. The adaptation pathways encompass adaptation options that span across different sectors, including research, land use planning, and transport to be implemented at several different levels (national, regional, local). The options involve the national government, regional authorities, as well as local companies and individual people

The three suggested pathways are intended to have different levels of **flexibility**, but the general methodology is flexible in itself: different adaptation options can be scheduled as they become relevant. Recommending the implementation of modeling

tools in our APs helps to inform this flexibility. The only hindrance occurs when adaptation options depend on the prior implementation of other (as yet unrealised) adaptation options. Some adaptation options are already intended for the national level, while other options have a regional character but can be easily applied to different regions. However, some options may depend on regional peculiarities and initiative, as well as financing, and may thus not be easily **scalable**.

Most of the individual adaptation options (especially categories 2 and 3) were developed based closely on **stakeholder** information. Stakeholder feedback was gathered to improve the description and the evaluation of the different adaptation options. However, the stakeholders did not directly contribute to the development of pathways.

If the most interventionist pathway was implemented, it would result in a **radical change**, especially based on the regulatory adaptation options such as resettling of people and movement of houses, schools and infrastructure in general. However, in the strongly democratic culture of Norway, such interventions depend significantly on public acceptance, and thus likely to a degree on peoples' perception of (climate-related) changes.

The specific needs of **vulnerable groups** was not actively considered. Marginalised communities in northern Norway may refer for example to municipalities which depend on a single access road, or indigenous people like the Sami whose culture largely depends on the use of uncultivated wilderness (e.g. for their reindeer herding). These

communities are especially affected by avalanche hazards, and improved avalanche warnings and forecasting will be especially beneficial for them. Land use change may also affect these communities which need to be actively consulted.

TRANSFORMATION ELEMENT	SCORE
TEMPORALITY: long-term vision/expected to produce long-term and durable outcomes	5
DEPTH OF CHANGE: Novel approach for the region	4
SCOPE: The AP includes a multi-sector approach	4
SCOPE: Responsive (flexible) to changing conditions	4
SCOPE: Developed at scale or easily scalable	3
INCLUSIVITY: Co-developed/discussed with stakeholders	3
DEPTH OF CHANGE: Expected to generate radical shift or large restructuring in your region	2
INCLUSIVITY: Consideration for the equity of measures, attention for vulnerable groups	1

IMPACT OF TRANSFORMATION

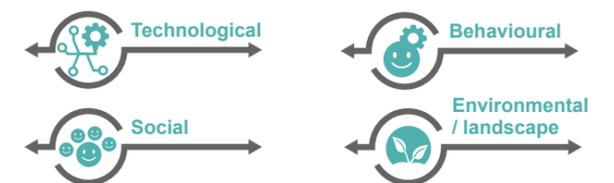
If implemented, adaptation pathways are expected to generate:

Behavioural transformation: People will become more aware of the character of the avalanche danger in northern Norway and learn to consult and understand and take seriously the national avalanche warnings, as well as learn to use the tools provided (such as ski-tour apps for mobile phones).

Social transformation: connected to behavioural transformation, there will be a more aware acceptance of risk and the acquiescence to regulatory changes implying the resettling of people from increasingly hazardous areas.

Technological transformation: new technologies will be made available and used by people, such as mobile phone applications to help choosing relatively safe ski tours or keeping the public updated on the regional danger level. Other new and helpful technologies may be machine-learning methods to help forecast the regional danger levels.

Landscape transformation: new defence structures will stop, divert, or prevent the release of avalanches. Depending on the size and scope of the structures, they may change the local landscape significantly. If protection from avalanches also includes afforestation ("nature-based" solution) this can also generate strong landscape impacts.



A PORTFOLIO OF CLIMATE ADAPTATION SOLUTIONS

Content

Nineteen adaptation solutions were assessed to address climate change in the Troms county of Norway. Six solutions were also developed and/or tested in IMPETUS.

In order to facilitate comparison among the large variety of adaptation options considered across all DSs, adaptation options were categorised according to the Key-Type-of-Measure (KTM) system, defined at the European level (Leitner et al., 2021) as voluntary mechanism to report climate adaptation actions in the EEA member countries, as part of the EU Regulation on Governance of the Energy Union and Climate Action Energy Union Governance Regulation (2018/1999).

Seven solutions belong to the category C2- Technological options, being related to the upgrade of the existing early warning systems and hazard mapping. Connected to these technological options, other solutions enhance capacity building (E2) by: providing guidelines for slushflow forecasting, favouring knowledge exchange and training ski guides.

Information and awareness raising solutions are also included, by providing new knowledge that can be used as decision support system (e.g. supporting the marine spatial planning) and by improving communication to people about the new risks posed by climate change.

For the governance and institutional category, the proposal of a new regulation is included to address the new climate change risks for existing buildings and infrastructure located in hazard zones.

Evaluation

All solutions will produce several social benefits, including: a decreased number of accidents and rescue operations, reduced losses and damages and new revenues for a more attractive and safer tourism. There is a strong need for data collection and research to implement the identified adaptation measures, as well as more accurate model simulation and machine learning models. Moreover, a collaborative environment for educating people, tourists and ski-guide is strongly encouraged.



OPTION	DESCRIPTION	MAIN OBJECTIVE(S)	IMPETUS CLIMATE RISK	KEY TYPE OF MEASURE	TESTED IN IMPETUS
Marine spatial planning (MSP) tool	Digital twins to co-design a Marine Spatial Planning framework.	To forecast the local impacts of climate change in the marine environment and other drivers. To visualize different adaptation strategies and solutions.	Biodiversity Loss	A2 - Management and planning	Y
Digital Twin	A mix of technical tools for planning and engagement approaches, to climate-proofing Troms city centre and its infrastructure against sea level rise and flooding.	To develop a tool for visualising the threats posed by rising sea levels and flooding, how water will affect shared city spaces and infrastructure. To ensure that the process and outcomes of adaptation are based on updated knowledge shared through this tool, thus providing the basis for improved decisions.	Sea level rise and flooding	E1 - Information and awareness raising	Y
Citizen Jury Handbook	Guidance on how to set up a citizen jury targeting climate adaptation issues such as sea level rise and flooding at the city level.	To argue the potential for city administration to broaden participation through a citizen jury.	Sea level rise, flooding	E1 - Information and awareness raising	Developed byt not tested / implemented by non byt
VR Tool	VR visualisation of future sea level and impacts on basic city infrastructure.	To enhance understanding of future risks.	Sea level rise	E1 - Information and awareness raising	Y
Avalanches EWS: Implementing machine-learning model	Machine-learning model trained on past avalanche warnings.	To improve the prediction of avalanche level based on meteorological and snowpack data to support human experts in their decisions.	Avalanche increase	C2 - Technological options	Y
Avalanches EWS: Implementing a snowpack model	Physically based multi-layered snowpack model, providing information on snow-pack stratigraphy.	To provide additional information on snowpack stability. To increase data availability and quality for avalanche forecasters.	Avalanche increase	C2 - Technological options	Y
Avalanches EWS: Decreasing the size of avalanche warning regions	Improvement of avalanche warning resolution.	To improve precision and lead to higher-quality avalanche warnings.	Avalanche increase	C2 - Technological options	
Avalanches EWS: Guidelines for site-specific slushflow forecasting	Manual with guidelines on how to detect and react to developing slushflows.	To provide additional competence of those responsible and increase safety of people.	Avalanche increase	E2 - capacity building, empowering and lifestyle actions	
Avalanches EWS: Seasonal prediction	Seasonal prediction models to infer tendencies in avalanche activity already one year into the future, providing information for planning efforts and preparation for the coming avalanche season.	To enable development of seasonal avalanche danger prediction.	Avalanche increase	C2 - Technological options	
Improvement of danger/risk communication: Avalanche terrain exposure scale map	Avalanche Terrain Exposure Scale (ATES) map categorizing the terrain into different scales of exposure to avalanches.	Produce avalanche-risk information for skiers and mountain users.	Avalanche increase	E1 - Information and awareness raising	
Improvement of danger/risk communication: Local avalanche guide meetings	Daily local avalanche guide meetings, where guides are invited to share their knowledge on the current risk situation.	To exchange knowledge and experience in avalanche danger.	Avalanche increase	E2 - capacity building, empowering and lifestyle actions	
Improvement of danger/risk communication: Ski-run lists	Information on safe routes available in mobile apps.	To provide safe route-choice advices to help skiers choose less dangerous mountain tours, decreasing accidents.	Avalanche increase	E1 - Information and awareness raising	
Improvement of danger/risk communication: Strategic ploughing of parking lots	Strategically deciding on whether to remove snow from parking lots close to ski-slopes at risks (based on guides' judgement of dangerous avalanche terrain).	To discourage skiers to access dangerous areas.	Avalanche increase	C1 - Grey options	
Improvement of danger/risk communication: Increasing the number of skilled ski-guides	Expanding the possibility to have training and certificates for ski guides (currently limited to one organisation in Norway).	To build capacity and educate ski-guides, improve the working conditions of ski-guides (e.g. offering year-round employment).	Avalanche increase	E2 - capacity building, empowering and lifestyle actions	
Hazard mapping and regulation: Hazard maps for slushflows	Including slushflow hazards in the national hazard map.	To improve information about possible source and extent of slushfow occurrences.	Avalanche increase	C2 - Technological options	(*)
Hazard mapping and regulation: Hazard map update for climate change	Upgrade of hazard maps by including more information related to climate change projections.	To improve information about areas subject to possible avalanche occurrences.	Avalanche increase	C2 - Technological options	
Hazard mapping and regulation: Expanding hazard mapping	Expanding the extent of the hazard map coverage.	To improve spatial coverage of hazard maps, including areas that are not currently mapped but host infrastructure.	Avalanche increase	C2 - Technological options	
Hazard mapping and regulation: New regulation concerning existing buildings in hazard zones	Development of new regulations to address existing infrastructure located in avalanche prone areas whose extension is expected to increase due to climate change.	To protect existence infrastructure situated in exposed areas.	Avalanche increase	A1 - Policy instruments	
Construction and avoidance measures	Expanding the spatial coverage of various structural measures. They include tunnels, barriers, and automatic road closures; remote Avalanche Controle towers (RACs), avalanche fences, protective forests and wind bluffs.	To reduce the exposure of people and infrastructure in hazardous areas To reduce the probability of hazardous events.	Avalanche increase	C1 - Grey options	

(*) Within the IMPETUS project, the feasibility of adapting different simulation tools to represent slushflow runoff is being explored.

#	Synthetic name of the option	ASSESSMENT												GAPS & NEEDS for implementation		
		Effectiveness for the expected objective	Lifetime	Feasibility - TRL	Feasibility - SRL	Economic costs	Benefits	Evaluate Environmental benefits	Evaluate Social benefits	Negative unintended effects/hidden risks	Evaluate Environmental negative unintended effects/hidden risks	Evaluate Social unintended effects/hidden risks	Implementation time		Synergy with mitigation	
1	Marine spatial planning (MSP) tool T4.19	+++	+	++	--		To help with coastal zone planning. E.g. forecasting drivers and local impacts of climate change in the coastal environment, visualizing different adaptation strategies and solutions.	+	+++	none					Yes	Access to data may be difficult because of ownership and sensitivity. Data owned by the industry may be restricted due to commercial reasons, and some national data, for instance detailed seafloor data, might be restricted due to national security reasons. Implementation in planning requires both institutional willingness and some.
2	Digital Twin T4.11	+++	+	+++	+		To assist municipal/urban planning, e.g. analysing the effects and local impacts of climate change (sea level rise, flooding) in the urban area.	+	++	none					Yes	Governance: Actual use of the DT remains to be assessed in the upcoming years. Finance: maintenance si not secured in the longer run.
3	Citizen Jury Handbook T4.11	++	++	+++	++		Will enhance inclusionary participation, broad learning, improved decisionmaking and legitimacy.	++	++	potential for increased conflicts				--	Yes	Finance: how to fund the process. Capacity: understaffed planning administration. Governance: how to channel the output of CJ into decision making.
4	VR Tool T4.11	++	+	+++	+		To assist municipal/urban planning, by visualising the effects and local impacts of climate change (sea level rise, flooding) in the urban area.	++	++	none					Yes	Finance: How to update the data and bring them into VR. Governance: How to make this form of knowledge dissemination the basis of decision making.
5	Avalanches EWS: Implementing machinelearning model T4.12	+++	+++	++	+++	-	Decrease number of accidents and rescue operations.		+++	none				--	No	The implementation of a machine learning (ML) model to improve prediction of avalanche danger may require a prior implementation of a snowpack model.
6	Avalanches EWS: Implementing a snowpack model T4.12	+++	+++	+++	++	-	Provide higher resolution avalanche warnings. Improve predictive skills of Machine-learning models.			none					No	
7	Avalanches EWS: Decreasing the size of avalanche warning regions. T4.12	+++	+++	++	+++	-	Provide higher resolution avalanche warnings. Improve accuracy of Machine-learning models.		++	none				--	No	Enabling conditions for the success of this measures include the implementation of machine-learning methods to predict avalanche danger level and the application of a snowpack model to provide more information on snow stratigraphy, together with increasing resolution of numerical weather prediction.
8	Avalanches EWS: Guidelines for site-specific slushflow forecasting T4.12	+++	+++	++	++	-	Decrease costs of damages from slush-flow.		++	none				--	No	Need for data collection/Research.
9	Avalanches EWS: Seasonal prediction T4.12	++	+++	+	++	-	Help long-term holiday planning.		+	Overconfidence in seasonal forecasts may lead to lack of preparedness.				---	No	Need for data collection/Research.
10	Improvement of danger/risk communication: Avalanche terrain exposure scale map	++	+++	++	+++	--	Decrease number of accidents and rescue operations.		+++	none					No	
11	Improvement of danger/risk communication: Local avalanche guide meetings	+++	+++	+++	+++	-	Improvements in national avalanche danger warnings.		++	none					No	
12	Improvement of danger/risk communication: Ski-run lists	++	+++	+++	++	-	Decrease number of accidents and rescue operations.		+++	none					No	Need for knowledge sharing among ski guides.
13	Improvement of danger/risk communication: Strategic ploughing of parking lots	++	+++	+++	++	-	Increased knowledge and control of road traffic during winter.		+	Dissatisfied citizens and tourists.					No	Need for knowledge sharing among ski guides.
14	Improvement of danger/risk communication: Increasing the number of skilled skiguidees	++	+++	+++	+++	--	Knowledge tranfer to skiers will improve awareness on avalanche-risk. Increase in revenue from ski tourism. More educated guides.		++	Increase in tourism and generic increase in people on mountains.				--	No	
15	Hazard mapping and regulation: Hazard maps for slushflows	+	+++	++	+++	-	Reduce knowledge gaps on slush-flow. Provide more information to recreational users.		+	Major costs to protect critical infrastructure buildings, such as hospitals and schools.			--		No	Need for the development of a robust simulation model for slushflows that realistically calculates where in the terrain the flow may travel.
16	Hazard mapping and regulation: Hazard map update for climate change	++	++	++	++	---	Increase well-being. Increase knowledge for insurance sector.		+	Increase in regulations on buildings and roads.			--		No	
17	Hazard mapping and regulation: Expanding hazard mapping	++	+++	+++	+	--	Increase well-being. Increase knowledge for insurance sector.		+	Change in property value.			---	---	No	
18	Hazard mapping and regulation: New regulation concerning existing buildings in hazard zones	+++	+++	+++	+	---	Increase well-being and safety management.		+	Some risk reduction strategie will include building, which may damage the environment. Maintenance costs.			--		No	Need for running simulations of avalanche runouts, and taking local knowledge, expert judgments and a history of events in the area into account. Need for coarser simulation models for indicative hazard maps, as alternative cheapest solution.
19	Construction and avoidance measures	+++	++	+++	+++	--	Protection from multiple mass movement types. Generate data and close knowledge gaps.		+	Impacts on landscape and biodiversity. Aesthetic losses.				--	No	

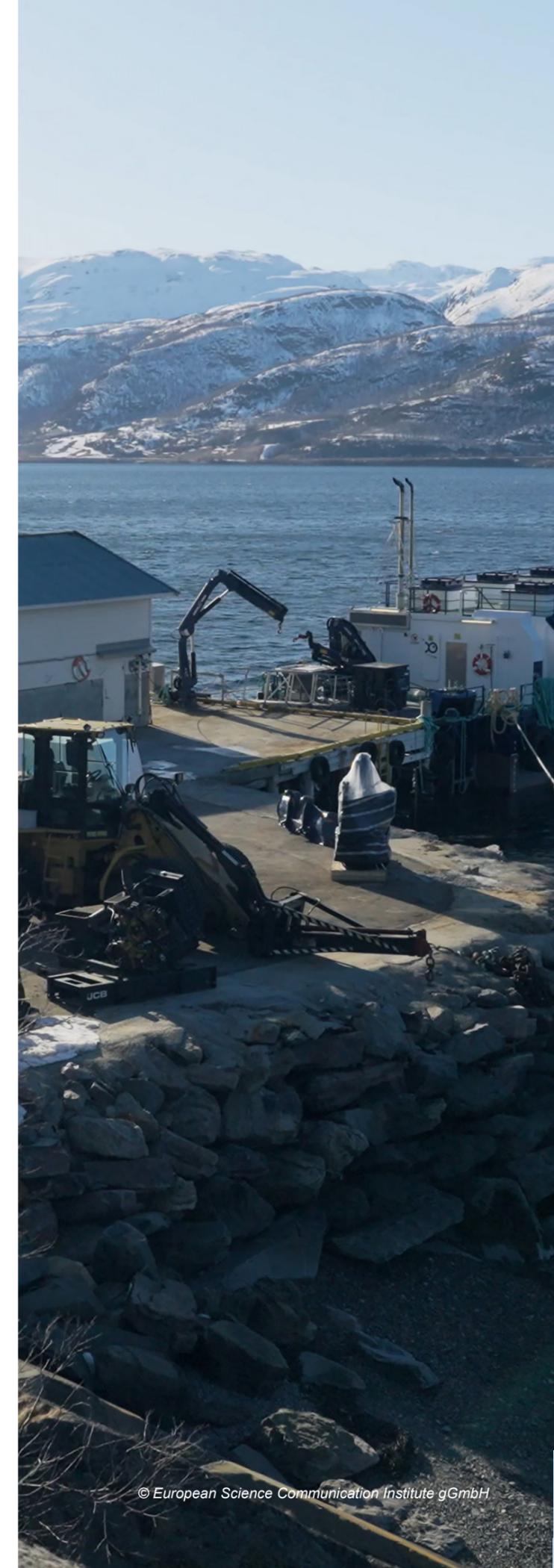
Portfolio of solutions - Transformational potential

ELEMENTS OF TRANSFORMATION

The portfolio of measures outlines a quite good potential for transformation, as the average scoring of all solutions is 3.3 (on a scale of 5). In particular, there is a high expectation for long-term and durable outcomes produced by almost all measures. Scalability is also a feature of several adaptation options that can be adapted to export to other regions or cover larger regions in northernmost territories. The weakest characteristic is inclusiveness, since no specific consideration was made for ensuring the equity of the measures and for voicing the most exposed and sensitive groups, with the valuable exception of the Citizen Jury Handbook.

Among the most transformational measures, those oriented to improve the hazard mapping (e.g. by incorporating climate change issues and the changing characteristics of avalanches) are considered an innovative and adaptive tool. They are also easily scalable, allowing to progressively incorporate new areas in the mapping geographical scope.

Synthetic name of the option	SCOPE			DEPTH OF CHANGE		INCLUSIVITY		TEMPORALITY
	Include a multi-sector approach	Responsive to changing climatic conditions	Developed at scale or easily scalable	Novel for the region	Expected to generate radical shift or large restructuring	Co-developed/discussed with stakeholders	Consideration for the equity of the measure with specific attention to vulnerable groups, marginalised communities and gender balance	Expected to produce long-term and durable outcomes
Marine spatial planning (MSP) tool	3	4	4	4	3	3	2	3
Digital Twin	5	4	4	4	3	5	2	4
Citizen Jury Handbook	5	4	4	5	N/A	3	4	N/A
VR Tool	2	5	5	4	3	3	2	N/A
Avalanches EWS: Implementing machine-learning model	2	3	4	5	1	2	1	4
Avalanches EWS: Implementing a snowpack model	2	4	5	5	1	2	1	5
Avalanches EWS: Decreasing the size of avalanche warning regions.	1	4	3	5	2	2	1	5
Avalanches EWS: Guidelines for site-specific slushflow forecasting	2	4	5	5	3	2	1	4
Avalanches EWS: Seasonal prediction	2	2	2	5	1	1	1	2
Improvement of danger/risk communication: Avalanche terrain exposure scale map	3	4	5	3	2	4	1	4
Improvement of danger/risk communication: Local avalanche guide meetings	3	not applicable	3	3	3	5	1	
Improvement of danger/risk communication: Ski-run lists	3	4	3	3	3	5	1	4
Improvement of danger/risk communication: Strategic ploughing of parking lots	3	4	4	3	3	5	1	4
Improvement of danger/risk communication: Increasing the number of skilled ski-guides	4	not applicable	4	3	3	5	1	4
Hazard mapping and regulation: Hazard maps for slushflows	4	4	5	5	3	2	1	5
Hazard mapping and regulation: Hazard map update for climate change	4	5	5	5	3	3	1	5
Hazard mapping and regulation: Expanding hazard mapping	4	4	5	2	3	3	1	4
Hazard mapping and regulation: New regulation concerning existing buildings in hazard zones	4	4	3	2	5	5	1	5
Construction and avoidance measures	3	3	3	1	3	5	1	4



Portfolio of solutions - Transformational potential

IMPACT OF TRANSFORMATION

The majority of solutions, if implemented in the Troms county, would especially bring institutional transformation, requiring for example significant changes in the hazard mapping system and the related regulation for buildings in risk prone areas. Institutional change would be also needed

to improve ski-guide training and for making more informed decisions in the marine space. Institutional transformation is followed by technological transformation, since significant technological upgrades are key to improve the avalanche forecasts and the early warning system.

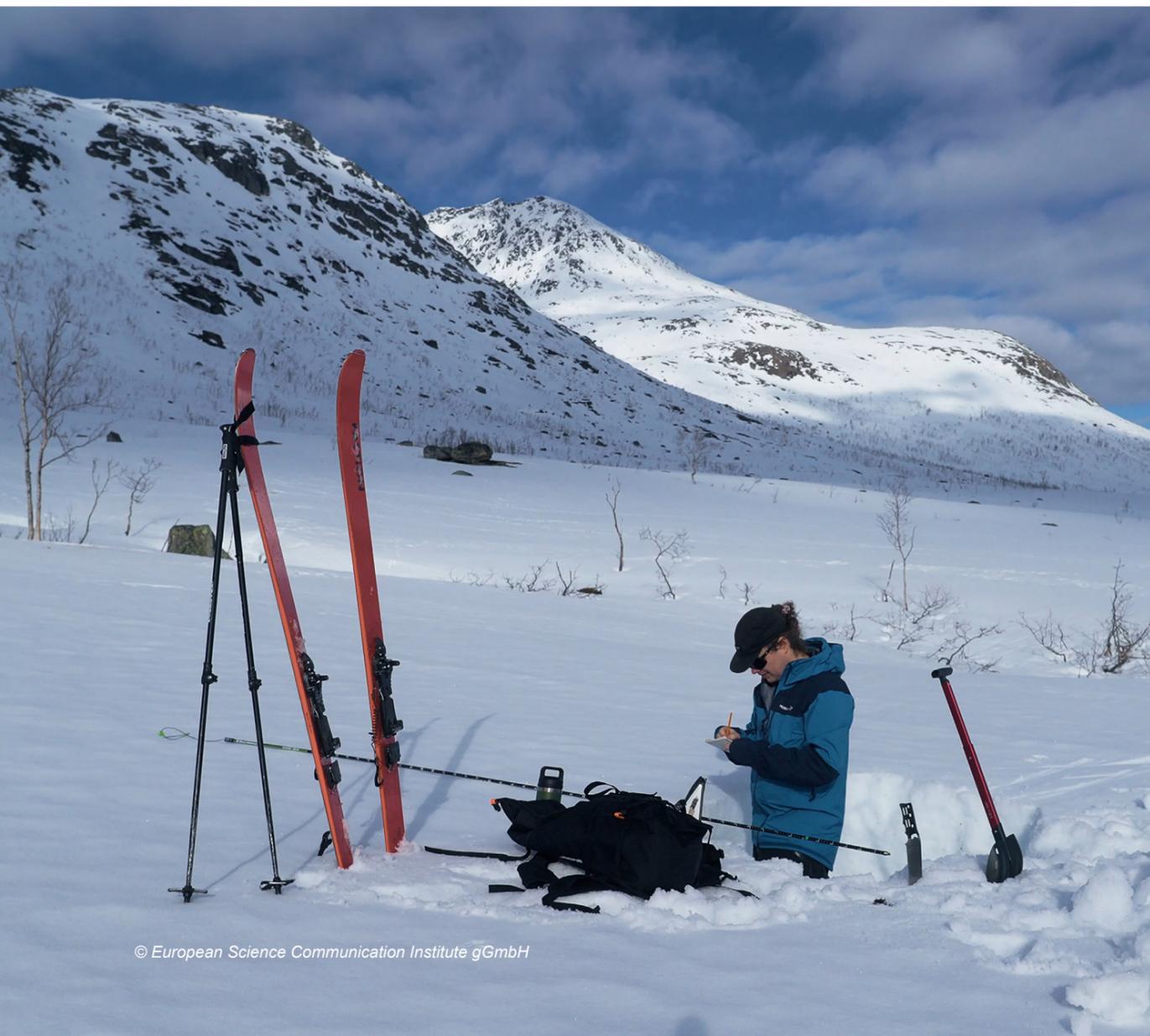
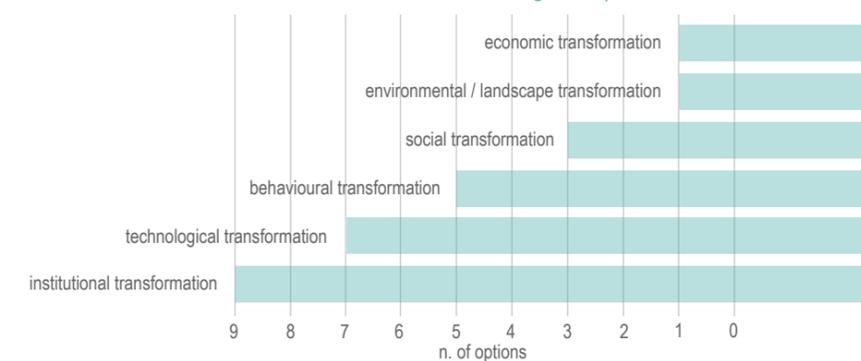


Figure: Impacted sectors



IMPACT OF TRANSFORMATION						
Synthetic name of the option	Economic transformation	Technological Transformation	Social transformation	Institutional transformation	Behavioural transformation	Environmental / Landscape transformation
Marine spatial planning (MSP) tool			X	X	X	
Digital Twin		X		X		
Citizen Jury Handbook			X	X	X	
VR Tool	X	X				
Avalanches EWS: Implementing machine-learning model		X		X		
Avalanches EWS: Implementing a snowpack model		X				
Avalanches EWS: Decreasing the size of avalanche warning regions.		X				
Avalanches EWS: Guidelines for site-specific slushflow forecasting		X				
Avalanches EWS: Seasonal prediction		X				
Improvement of danger/risk communication: Avalanche terrain exposure scale map					X	
Improvement of danger/risk communication: Local avalanche guide meetings				X		
Improvement of danger/risk communication: Ski-run lists					X	
Improvement of danger/risk communication: Strategic ploughing of parking lots					X	
Improvement of danger/risk communication: Increasing the number of skilled ski-guides				X		
Hazard mapping and regulation: Hazard maps for slushflows				X		
Hazard mapping and regulation: Hazard map update for climate change				X		
Hazard mapping and regulation: Expanding hazard mapping				X		
Hazard mapping and regulation: New regulation concerning existing buildings in hazard zones			X			
Construction and avoidance measures						X

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Turning climate commitments into action